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Subject: Letter Progress Report of Work Under Contract No. NASr-54(06) for the Period 1 December 1965 to 28 February 1966

Gentlemen:

This status report covers the work during the period from 1 December 1965 to 28 February 1966 under Contract No. NASr-54(06), Man-Machine Performance Measurements. By the end of this period approximately 71% of the budgeted funds for the first and second years have been expended.

Work is continuing on the conduct and analysis of experimental studies of human performance characteristics in manual control tasks; and on the developments of techniques for manual control system simulation and data analysis.

1. EXPERIMENTAL STUDIES

Operator Performance in Two-State Relay-Control Systems

A formal experiment (66-1) has been initiated to extend the results of previous work using the two-state relay-control system to study the ability of subjects to monitor and control an on-going response sequence. In the previous work, it appeared that subjects could monitor the temporal organization of response sequences at a level removed from the point for point response generation process. The question now being explored is the extent to which a skilled subject can exert control when he is required in addition to null out the perturbing effects of an external input. In the training phase of the study, four skilled drummers are being given approximately ten hours of practice in controlling an acceleration system (K/s^2) by the manual operation of two keys. They were trained with two values of system gain K, 45 and 100 cm/sec^2. After the ten days of training, external inputs were introduced in order to determine the subject's ability to compensate for these disturbances while maintaining his rapid response rate. These inputs were sine waves and triangular waves of 0.1 and 0.2 cycles per second and were introduced at each of the two gain settings. These conditions were run in a factorial design for an additional nine days. The data collection in this experiment has been

completed and analysis has begun. We expect to obtain information about how the operator manages two levels of control simultaneously, that is, (1) maintenance of high rates of responding and (2) higher-level control over the disturbance inputs.

Operator Performance With Predictable Input Signals

Experiment 65-7, referred to in an earlier progress report, which examines the role of manipulator dynamics in shaping the error power spectrum has been completed. This experiment demonstrated that the high-frequency cutoff of the band of noise power that is present in the operator's output is sensitive to the magnitude of the spring restoring torques and the inertia of the control stick and also to the level of tension that the operator is instructed to employ in manipulating the stick. When the condition of high inertia, low spring constant was compared with the condition of low inertia, high spring constant, the high-frequency cutoff of the noise spectrum shifted from 3 cps to 2 cps, a rather significant change in the direction that reflects the mechanical filtering effect of the control stick. The variable of operator tension was also shown to effect the dynamics of the arm and control stick taken together, but the magnitude of the change was small. In addition to the theoretical importance of specifying the variables controlling the characteristics of this operator noise, these results suggest mechanical or electrical filtering as a practical means for minimizing the deleterious effects of this noise in tracking systems when input signal bandwidth is below one or two radians/sec.

In Experiment 66-2 the general results of the sine-wave tracking experiments described previously have been extended to the case of pure ramp inputs. Four subjects were required to track constant velocity input signals of 1, 2, and 4 cm/sec. at each of two control gain settings using a pursuit display. In a second part of the study, the subjects were required to generate a constant velocity during a period of time when the constant velocity input signal was blanked from the display. The presence of noise in the operator's output, exactly in parallel with the results of the sine-wave tracking experiments, was observed; however, one further generalization was possible. Under all combinations of control gain and input velocity there appeared to be little change in the frequency distribution of the noise. However, with increasing velocity the noise amplitude was increased. These results tend to rule out a formulation of tracking performance based on the operation of a threshold device in which the operator waits until the error exceeds a certain threshold and then makes a discrete correction. Under such a hypothesis, the frequency or periodicity of the noise should be directly proportional to the ramp velocity. Blanking the velocity input signal produced overall poorer tracking performance as might be expected, but no detectable changes in the output noise characteristics were observed.

Miss Margaret Robb has completed a Ph.D. thesis in physical education with support from this project. In Experiment 65-3 described in a previous progress report, she has studied several alternative means for training subjects in the performance of a specific predictable movement pattern having a total duration of approximately 4 seconds. Such precision

response patterns might be required in a complex attitude maneuver of a spacecraft. In the criterion test trials subjects were required to perform this pre-programmed maneuver without the aid of command information, that is they were required to produce the movement pattern, not to track a target. Several alternative modes of training were used which included the opportunity to perform the movement as a pursuit tracking task. It was found that the presentation of visual command information during the practice trials produced no better performance during the test phase than practice without such command information. Further it was shown that practicing the movement pattern with a slowed down time scale during the training period produced significantly worse performance on the criterion test trials. It appeared in general that providing knowledge of results at the end of each training trial was as effective for improving performance on the criterion test as was providing point by point error information about the subject's performance within each trial. A contractor report describing this experiment in detail is in preparation.

Validation Data for Parameter-Tracking Models

In conjunction with the development of a two-parameter tracking model to be described in a later section, a collection of validating data has been initiated. In Experiment 66-3 three subjects performed a compensatory tracking task with controlled element dynamics of 5/s. Three random forcing functions were used having cutoff frequencies of 1, 2, and 4 radians/sec. Significant learning occurred during the ten days of practice, especially at the higher input bandwidths. These data are being analyzed by a parameter-tracking model to determine the values of gain and time delay associated with various phases of learning.

2. DEVELOPMENT OF DATA ANALYSIS AND SIMULATION TECHNIQUES

Development of Parameter-Tracking Models

Mr. Jackson's work on parameter-tracking models has focused on the development of a two-parameter tracking representation of the McRuer cross-over model having the form $\frac{Ke^{-\tau s}}{s}$. McRuer has shown for relatively simple plants that a model of this form provides an adequate representation of the performance of the open-loop combination of operator and plant with K and τ being the significant parameters. For implementation on the analog computer, the first order Pade approximation, $e^{-\tau s} \approx \frac{\frac{2}{\tau} - s}{\frac{2}{\tau} + s}$ was used. The closed-loop output of the system containing the operator and all dynamics was compared to the closed-loop output of the system in which the entire forward loop was the cross-over model. K and τ were continuously adjusted to minimize an index of performance based on this difference. Analysis of the random-input-signal compensatory-tracking data from Experiment 66-3 by means of this model is underway.

Predictive Display Development and Evaluation

Mr. John Warner is initiating a Ph.D. thesis in Information and Control Engineering, under the subject contract, that will investigate the usefulness of the predictive display concept in which a fast-time model of the system to be controlled makes possible predictions of the future state of a system as a result of the currently implemented control actions. Simulation of the plant to be controlled, generation of the displays and generation of the on-line data processing are being implemented on a logic-controlled analog computer. As the starting point for these investigations, a pure inertia plant is being simulated. A display has been mechanized in which the vertical axis represents a time scale into the future and the horizontal axis is a compensatory error display. One of the goals of the initial work with this system is to determine a set of non-dimensional parameters related to both display and plant variables which will permit generalization for the results beyond the specific parameters used in any particular experiment. Such a development is needed if predictive display design guides are to be established.

Simulation Methods

Research has continued on improved simulation methods, with effort devoted to application of constraints to improve high-speed computation accuracy. A method for constraining five of the six integrals of the equations of motion has been developed, but there are bothersome singularities which restrict the usefulness of the resulting solution. Work will continue to try to alleviate the singularity problem.

A paper on function generation methods has been written and will be submitted for publication.

3. RELATED ACTIVITIES

Drs. Fogarty and Pew attend the NASA-MIT Annual Working Conference on Manual Control held at the end of February. Dr. Pew presented a paper entitled: "Sine-Wave Tracking Revisited" which describes the major results of Experiment 65-2. This paper will appear in the published proceedings of this conference.

Personnel

During this reporting period the following personnel have charged time to the subject contract:

	Fraction of Time
L. E. Fogarty	.50
R. M. Howe	.10
R. W. Pew	.40
T. Armstrong	.50
J. Duffendack	.35
L. Fensch	1.00

J. Frait	.50
R. Gilson	.50
J. Overmars	.40
R. Rapley	.50
M. Rash	.33
M. Robb	.50
J. Warner	.50

Mr. James Herzog and Mr. Glen Jackson are participating in the work of the program under a NASA Traineeship and a Ford Foundation Fellowship, respectively.

Sincerely yours,

Robert M. Howe

Robert M. Howe
Information and Control
Engineering
Department of Aerospace
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Richard W. Pew

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Co-Principal Investigators

RWP/mr